RESEARCH-ARTICLE

DISCOV.ER: Digital Twin and Citizen Science for the Sustainability of Areas of Natural and Tourist Interest

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Abstract

Climate change is increasingly affecting both human activities and natural ecosystems, putting pressure on environmental stability and causing biodiversity loss. In this context, the Po Delta, an ecologically sensitive area in Italy comprising an UNESCO site and three Ramsar-designated wetland sites, faces challenges related to rising sea levels, salinity shifts, and pollution caused by human activities. The *DISCOV.ER* project tackles these issues by developing innovative technologies aimed at supporting sustainable management and increasing public awareness. At the core of the project is a digital twin fed by (i) heterogeneous data sources, including real-time environmental sensors and multimedia content, (ii) AI-powered insights and predictions, and (iii) participatory data collected through citizen science. The platform also integrates interactive services based on game thinking and data visualization to engage citizens and visitors with biodiversity and sustainability topics and promote ecotourism. In this paper, we present the research framework guiding the project and provide an overview of the activities conducted thus far, including the design and installation of the sensing infrastructure, the co-design of citizen science tools through interviews and surveys, and the development of the digital twin platform to aggregate and present the data of our digital twin.

CCS Concepts

• **Human-centered computing** → **Social engineering (social sciences)**; • **Hardware** → **Sensor applications and deployments**; • **Applied computing** → *Environmental sciences.*

Keywords

Digital Twin, Citizen Science, Sustainability, Ecotourism, Biodiversity Preservation

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1 Introduction

The acceleration of climate change and environmental degradation is one of the global trends with the most dramatic repercussions across multiple dimensions of human life, including health, security, economy, and ecosystem stability. According to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report [9], human-induced climate change is now widespread, rapid, and intensifying in every region of the world, at a scale that is unprecedented in at least the last two millennia. The climate change phenomenon not only affects human lives [1, 13, 23], but also places immense pressure on natural ecosystems and biodiversity [8]. Protected areas of ecological relevance are particularly at risk, as the effects of climate change exacerbate existing vulnerabilities caused by human activities [6, 22].

Preserving biodiversity and promoting environmental resilience under these conditions demands innovative, anticipatory approaches based on environmental intelligence and data-informed decision-making [19]. Consequently, digital technologies are increasingly seen as key enablers in this effort [7]. From sensor networks and satellite observation [2, 17] to advanced data integration platforms [5] and citizen science initiatives [3, 11], technological tools can provide a more detailed and dynamic understanding of environmental systems [24]. Beyond supporting decision-makers [16], these tools can also engage citizens and tourists, enhancing public awareness, encouraging sustainable behaviors, and promoting ecotourism [4].

The DISCOV.ER project[1] was conceived to address the complex challenges posed by climate change and biodiversity loss with an interdisciplinary and participatory approach. It aims to develop innovative digital solutions that integrate environmental sensing, data visualisation, game thinking, and citizen and stakeholder engagement. The goal is twofold: to provide experts and policy-makers with tools for monitoring, forecasting, and decision-making, and to increase public awareness through immersive technologies that promote sustainability, environmental stewardship, and ecotourism.

Of particular relevance for this initiative is the Po Delta, located in northern Italy, as one of the most ecologically significant areas

[1] https://www.discover-project.it/

in Europe. This ecosystem supports a wide range of biodiversity, including a colony of more than 10,000 pink flamingos and over 360 other species of birds. Recognized internationally for its ecological and cultural value, the Po Delta incorporates a UNESCO World Heritage site, along with three Ramsar-designated wetland sites [20]. Despite its natural value, the Delta is under considerable pressure. It lies within the broader Po Valley, one of the most polluted regions in Europe, and is increasingly vulnerable to the effects of climate change [18]. The ecological balance of the Delta is delicately maintained through careful management of key environmental parameters, such as water levels and salinity, which are susceptible to disruption from climate change, extreme weather events, sea-level rise, and human activity, including tourism.

Within this context, the Po Delta serves as the primary case study for the DISCOV.ER project. Here, a digital twin will be co-designed with local stakeholders and enriched with heterogeneous data sources, including real-time sensor data and multimedia content gathered through citizen science. This integrated infrastructure will serve not only as a repository of environmental data but also as a dynamic system capable of producing insights through artificial intelligence and machine learning, to support forecasting, scenario simulations, and the identification of emerging patterns related to climate change and biodiversity loss. The project will also develop engaging interfaces for public users. Innovative services based on game thinking principles will be designed to motivate participation and environmental learning, while data visualization will enable both experts and non-experts to explore the state of the ecosystem in an intuitive and immersive manner. By doing this, the DISCOV.ER project aims to combine environmental intelligence with participatory engagement, supporting sustainable management, enhancing ecotourism, showcasing the cultural and natural heritage of the area, and fostering long-term environmental responsibility.

This paper outlines the research framework guiding the DISCOV.ER project and provides an overview of the progress achieved to date. It describes the methodologies we adopted, the initial technical implementations, and the participatory processes undertaken with local stakeholders, citizens, and tourists. Particular attention is given to the development of the sensing infrastructure, participatory monitoring initiatives, and early prototypes of the digital twin platform.

2 Research Framework

The objective of DISCOV.ER is developing a comprehensive digital twin of naturalistic and touristic areas within the Po Delta, to support informed decision-making and raise public awareness regarding biodiversity and climate change, while promoting ecotourism.

Core to the approach we adopted is the definition of digital twin as *"a living model of the physical asset or system, which continually adapts to operational changes based on the collected online data and information, and can forecast the future of the corresponding physical counterpart."* [12]. This definition highlights the relevance of gathering and integrating data from diverse sources, which is why our approach at DISCOV.ER combines data collected by exploiting environmental sensing monitors (Sec. 2.1) with participatory methods for environmental sustainability (Sec. 2.2), into a unified digital twin platform (Sec. 2.3).

Figure 1: Map of the sensing infrastructure deployed in the Comacchio Lagoon, comprising six weather and water monitoring stations (stations 1-6) and one fauna monitoring station (station 7). Icons indicate the specific hardware components installed at each station.

The project draws inspiration from the SMARTLAGOON[2] research initiative, which focused on the development of a digital twin for the Mar Menor lagoon in Spain to assist policymakers in managing complex environmental challenges [14]. DISCOV.ER builds upon the methodologies and results of SMARTLAGOON, applying them to a different ecological and socio-cultural context. The objective is twofold: to transfer and adapt best practices to the Po Delta Park and to advance the state of the art by creating scalable frameworks that can be applied to other regional and international natural heritage sites. Additionally, DISCOV.ER intends to go a step further by directly engaging stakeholders in the co-design of the digital twin and of the citizen tools, and exploiting such innovative technologies for promoting an informed ecotourism.

2.1 Environmental Sensing

To monitor key environmental parameters of the lagoon in real-time, we set up a distributed network of monitoring stations within the Po Delta Park. The infrastructure has been co-designed with local stakeholders to ensure alignment with operational needs. Furthermore, it's designed to minimize ecological disturbance, with each installation being tailored to the specific requirements of the corresponding monitoring site. As explained in detail in Section 3, we are using a combination of: i) weather and water monitoring stations, to gather environmental data, and ii) fauna monitoring stations, to track and observe key wildlife species within the park. The resulting data stream forms the physical backbone of the digital twin, enabling real-time monitoring, historical analysis of environmental trends, and forecasting future scenarios through AI and simulations.

[2]https://www.smartlagoon.eu/

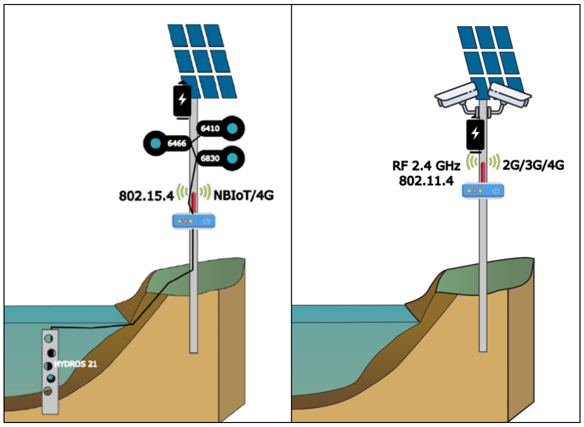

Figure 2: On the left, the illustration of a fully equipped weather and water monitoring station. On the right, a station dedicated to fauna observation.

2.2 Participatory Methods for Sustainability

DISCOV.ER promotes participatory environmental actions as a bottom-up approach where citizens and stakeholders are directly involved in the development of integrated solutions for environmental challenges, by integrating various forms of knowledge, including traditional, scientific, technical, and administrative. In particular, we envisioned taking advantage of two approaches: participatory environmental monitoring [21] and participatory environmental management [15]. For the monitoring aspect, we will co-design and develop an engaging mobile application for citizen science data collection. Our users will be encouraged to contribute multimedia data, such as photos and observations of local flora and fauna, which will be integrated into the digital twin.

For the management aspect, we will directly engage stakeholders in all phases of the development process, from the co-design to the evaluation of the sensors infrastructure and digital twin.

2.3 Digital Twin Platform

The digital twin platform serves as the integrative core of the project, aggregating information from sensors and citizen contributions and enriching it through data processing pipelines that will exploit AI and machine learning algorithms to analyze trends, simulate scenarios, and generate predictive insights on climate-related phenomena and biodiversity dynamics. The platform is also going to feature intuitive visualization tools and adaptive interfaces tailored to different types of users, from experts and policymakers, to the general public. This will ensure that the digital twin functions not only as a technical decision-support tool but also as a medium for education, outreach, and participatory governance.

3 Environmental Sensing Infrastructure

Following a series of participatory meetings with the Po Delta Park management (as part of the participatory environmental management strategy), we defined two core scopes for our sensing infrastructure: i) observation of hydrological and meteorological parameters, and ii) automated acquisition of multimedia content for fauna monitoring. These objectives are aligned with the broader goal of supporting biodiversity conservation and sustainable park management in the face of climate change and increasing anthropogenic pressures.

Table 1: List of the primary hardware components used in our sensing infrastructure, along with the corresponding station numbers where each component is installed.

Hardware	*Station*
Weather station	
Davis rain collector 6466	2, 3, 6
Davis anemometer 6410	2, 3, 6
Davis temperature/humidity sensor 6830	2, 3, 6
Water station	
Meter HYDROS 21 water probe	1 (2x), 2 (2x), 3, 4, 5, 6
Camera station	
Reconeyez 1920x1080 IR camera	7 (2x)
Passive PIR sensor	7
Communication	
Winet NBIoT/2G/3G/4G & 802.15.4	2, 3, 5, 6
Winet NOD-R-AQ 802.15.4	1, 4
Reconeyez Bridge 2G/3G/4G & 802.11.4	7
Power	
3W solar panel	1, 2, 3, 4, 5, 6
20W solar panel	7
6V 5Ah lithium battery	1, 2, 3, 4, 5, 6
3.7V 10Ah lithium battery	7

The park management emphasized the need for real-time monitoring of water parameters, particularly water levels and salinity, in several sensitive zones of the Comacchio lagoon. Water levels must be maintained within a narrow range, typically ±20cm relative to sea level, and preserving the salinity conditions is essential for biodiversity. In the lagoon, water and salinity levels are controlled by hydraulic structures that are manually operated by park employees and volunteers, using the Mediterranean Sea to increase salinity and the Reno River to reduce it. Water temperature is also closely monitored, as even small fluctuations can significantly affect the health of flora and fauna. The success of these operations depends heavily on timely and accurate knowledge of hydrological conditions, tides, and wind direction. In the absence of continuous monitoring, decisions have historically relied on manual measurements, which are labor-intensive, imprecise, and often require multiple interventions before achieving the desired balance.

The park management also expressed a strong interest in deploying systems for passive fauna observation. The Po Delta is recognized for its exceptional faunal diversity, including numerous species of birds, amphibians, and mammals. The ability to remotely monitor the presence, movement, and behavior of wildlife in strategic locations offers valuable insights for conservation planning, threat detection (e.g., invasive species), and adaptive management. One particularly critical area identified for fauna monitoring is located at the tip of the Boscoforte peninsula, an ecologically rich and physically isolated zone known for hosting large populations of flamingos and other migratory birds.

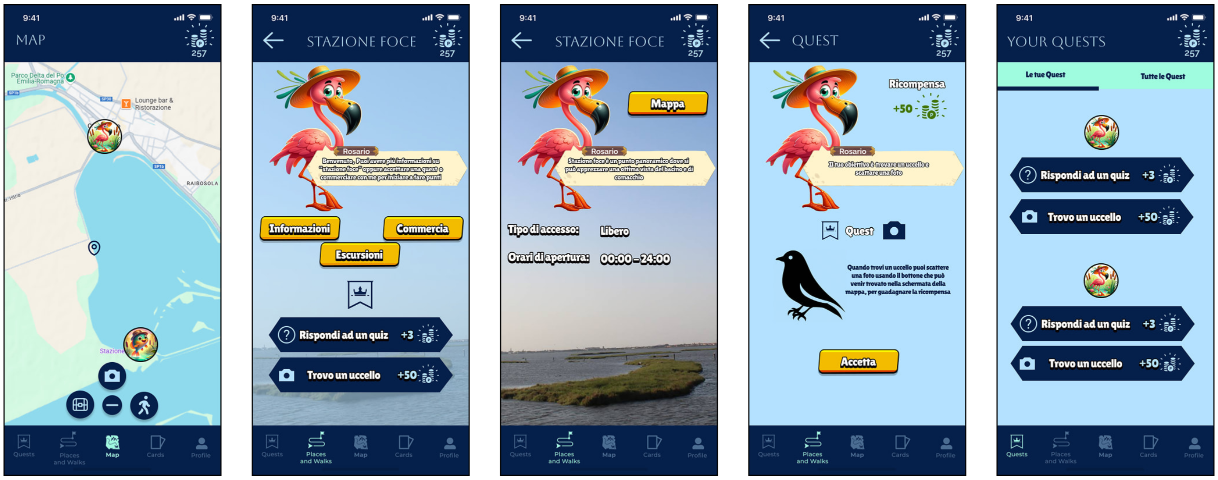

Figure 3: Experimental mockups of the citizen science app. From left to right: 1) the user views the locations of virtual characters on a park map; 2) the user interacts with a character represented as a flamingo; 3) the user requests information about a specific point of interest; 4) the user receives a quest from the flamingo; and 5) the user reviews active quests in their log.

Although technically challenging due to its remoteness, the site was prioritized given its importance.

To meet the defined monitoring requirements, six weather and water sensing stations were designed for deployment at key locations within the lagoon. Additionally, one installation point for a fauna monitoring station was identified in the Boscoforte peninsula. The map of our full sensing infrastructure is shown in Figure 1. The overall system design emphasizes minimal environmental impact and autonomous operation: all stations are off-grid, solar-powered, and produce zero emissions, both chemical and acoustic. Site access and installation scheduling were coordinated to avoid disturbance to sensitive wildlife periods, such as the flamingo nesting season. All infrastructure complies with relevant environmental regulations and follows the Do No Significant Harm (DNSH) principles [10].

3.1 Weather and Water Monitoring Stations

Each weather and water monitoring station includes a combination of sensors and communication modules tailored to site-specific requirements. A fully equipped monitoring station consists of the following components: a rain collector, an anemometer, air temperature and humidity sensors, a water quality probe capable of measuring temperature, level, and electrical conductivity (used as a proxy for salinity), a 4G router for data transmission, a 3W solar panel, and a 6V 5Ah battery. More details on the list of components are provided in Table 1 and a fully featured station is depicted in Figure 2 (left).

The configuration of the six stations varies depending on local needs. Three of the stations are installed near hydraulic structures and are equipped with dual water probes to monitor upstream and downstream conditions. Two installations are deployed in proximity to other stations and utilize IEEE 802.15.4 wireless communication, eliminating the need for individual 4G modules. Weather stations are installed only at three of the six sites, selected to provide representative meteorological data for the broader area. Refer to Figure 1 for a full picture of the properties of each installation.

The stations collected data every 15 minutes and send it via MQTT protocol to a centralized platform. The sampling interval was defined to provide a near-real-time representation of the lagoon's dynamic conditions while ensuring energy efficiency and battery autonomy for the entire duration of the project, thus minimizing maintenance requirements.

3.2 Fauna Monitoring Station

To support continuous observation of key wildlife species, a dedicated fauna monitoring station was be deployed at the Boscoforte peninsula site. The station is equipped with two high-resolution cameras featuring 960nm infrared LEDs with a 30m range, an infrared passive motion sensor (PIR) for motion-triggered recording, a 4G router, a 20W solar panel, and a 3.7V 10.2Ah battery. More details on the hardware components are listed in Table 1, while Figure 2 (right) presents the final equipment setup.

This station operates on a one-hour image capture cycle, using sFTP for secure media transmission. Just like with the other stations, the sampling rate was selected to balance the adequate wildlife activity monitoring with power constraints, aiming to sustain the system autonomously for the entire lifecycle of the project.

4 Participatory Environmental Monitoring

The main tool we'll exploit for participatory environmental monitoring will be a citizen science application. Users, both residents and tourists, will contribute data such as photos, reports, and geolocated observations, which will be integrated into the digital twin. At the same time, the app will give back to users by educating on biodiversity, ecotourism, and sustainable practices and, to keep users engaged over time, it will incorporate gamification elements such as challenges and rewards.

To guide the design of a citizen science application, we adopted a co-process involving both tourists and local residents (as part of the participatory environmental management strategy). A combination of online questionnaires and in-person interviews was used

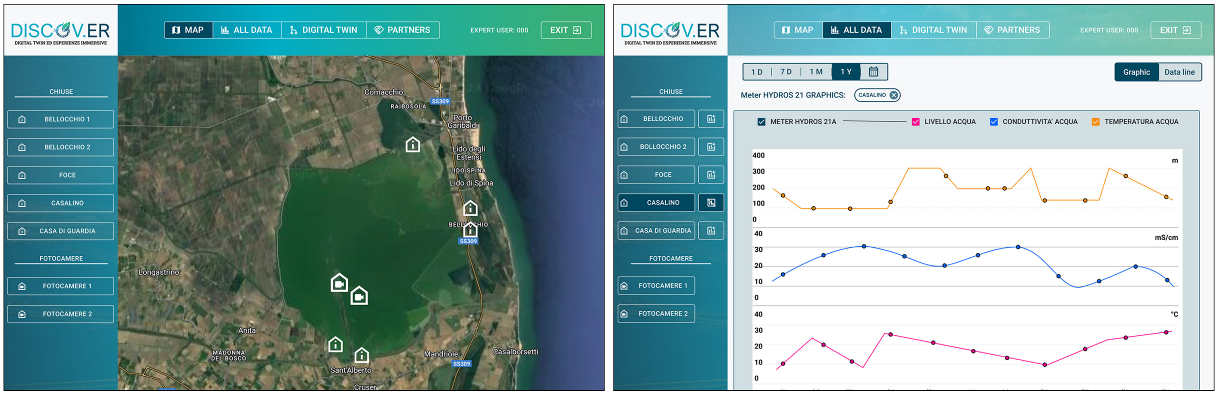

Figure 4: Prototype of the expert interface of our DT platform. On the left, the primary map-based view, providing access to all monitoring stations across the Comacchio Lagoon. On the right, a detailed chart view for a selected station, offering functionalities to filter data by time, compare it with other stations, or visualize it in tabular format.

to gather insights on user motivations, expectations, and preferred interaction models. The online questionnaire gathered responses from 173 participants. Results indicated a strong interest in the use of technology for environmental engagement, with 80% of respondents agreeing that digital tools can make learning about nature more compelling. When asked about features that would encourage them to use such an application, participants identified quality educational content (55%), challenges and goals (50%), rewards (45%), ease of use (39%), and opportunities for interaction with other users (30%) as key motivating factors. These findings were complemented by 16 in-person interviews conducted with park visitors. Most interviewees expressed interest in tracking the effects of climate change in the Po Delta (88%), staying informed about the local ecosystem through news and updates (94%), and accessing educational content in various formats such as articles, videos, or podcasts (63%).

Based on these insights, we developed a series of mock-ups for the citizen science application. One of the prototypes, showcased in Figure 3, features an augmented reality experience in which users encounter virtual characters distributed throughout the park. These characters, who are personified versions of animal species living in the area, task the users with quests, such as taking pictures of local flora and fauna, completing quizzes, or visiting key locations in the park. Upon completing a task, users receive collectible virtual cards themed around the park's biodiversity. These cards can be exchanged and shared, encouraging both individual exploration and social interaction. While the primary objective of the application is to raise awareness and promote sustainable behaviors, it also serves as a lightweight data collection tool. Anonymized observations and inputs gathered from users will be integrated into the digital twin platform to support a more comprehensive and participatory representation of the Po Delta ecosystem.

Once the application reaches a functional prototype stage, we plan to carry out user evaluations with both citizens and tourists to assess its usability, engagement, and educational impact. Feedback collected during this phase will be used to refine the app, ensuring that the final result aligns with user needs while maximizing its effectiveness as both an educational tool and a participatory environmental monitoring instrument.

5 Digital Twin Platform

Just as in the other work packages, the design of the digital twin platform follows a participatory approach (as part of the participatory environmental management strategy), incorporating insights and priorities gathered from stakeholders operating in the Po Delta territory. To this end, a dedicated co-design workshop was organized, involving six stakeholders with direct experience in the management, conservation, and promotion of the area. During the session, participants provided detailed accounts of current monitoring practices and identified opportunities where the digital twin could enhance their operations. Specific emphasis was placed on the management of hydraulic structures, which rely on manual monitoring and operation by volunteers. Their crucial role in preserving biodiversity in the Delta is explained in more detail in Section 3. Regarding the monitoring of flora, the workshop revealed how flamingo populations in the area are currently counted manually and tracked using numbered rings.

Based on this feedback, several key functionalities were identified for the digital twin. On the backend, we are working on artificial intelligence and machine learning techniques to automate the counting of animal populations from image data and to forecast critical environmental parameters such as water level, temperature, and salinity. As for the frontend, two main user profiles emerged: public users and expert users. The public interface will provide simplified visualizations aimed at raising awareness among citizens and tourists, while the expert view will be accessible through authentication and offer a more advanced map-based dashboard. This interface will enable access to both real-time and historical data from individual monitoring stations, with tools for comparing data across locations and browsing it through interactive charts or tables. A first prototype of the expert interface, which reflects these priorities and functionalities, is currently under development and is presented in Figure 4. Stakeholders involved in the design phase will also have the opportunity to provide their feedback during an evaluation of the prototype, directly informing subsequent iterations to improve the platform.

6 Conclusion

This paper presented the research framework and early developments of the DISCOV.ER project, which aims to integrate environmental sensing and participatory environmental monitoring into a digital twin of the Po Delta Park. The project combines real-time sensor data, citizen science contributions, and AI-based analysis to support climate resilience, biodiversity conservation, and sustainable ecotourism. All activities are tackled with a participatory approach, with stakeholders and citizens involved in the co-design of both technological infrastructure and user-facing applications. Preliminary results from participatory activities, including workshops with stakeholders and citizen engagement through questionnaires and interviews, highlight the potential of combining immersive technologies with environmental education. The integration of these components into a cohesive and functional digital twin is currently underway. Looking ahead, one key challenge will be maintaining long-term engagement from citizens and tourists, as the success of participatory monitoring depends on their continued interest and involvement. Additionally, integrating heterogeneous data sources - including sensors, AI outputs, and citizen science insights - into a coherent and reliable system will remain a central technical focus during the next stages of the project.

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